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Uncertainties of wild-land fires emission in AQMEII phase 2 case study

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HIGHLIGHTS

- Main uncertainties of wild-land fire emission estimates is discussed.
- Total emission can be over-estimated up to 50% with individual-fire emission accuracy.
- IS4FIRESv1 emissions in Europe are over-estimated in-average by 20–30%.
- Impact on total emissions probably comes from under-stated injection height.
- High-energy sources mis-interpreted by MODIS as fires bring about a few tens of %.

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ABSTRACT

The paper discusses the main uncertainties of wild-land fire emission estimates used in the AQMEII-II case study. The wild-land fire emission of particulate matter for the summer fire season of 2010 in Eurasia was generated by the Integrated System for wild-land Fires (IS4FIRES). The emission calculation procedure included two steps: bottom-up emission compilation from radiative energy of individual fires observed by MODIS instrument on-board of Terra and Aqua satellites; and top-down calibration of emission factors based on the comparison between observations and modelled results. The approach inherits various uncertainties originating from imperfect information on fires, inaccuracies of the inverse problem solution, and simplifications in the fire description. These are analysed in regard to the Eurasian fires in 2010. It is concluded that the total emission is likely to be over-estimated by up to 50% with individual-fire emission accuracy likely to vary in a wide range. The first results of the new IS4FIRESv2 products and fire-resolving modelling are discussed in application to the 2010 events. It is shown that the new emission estimates have similar patterns but are lower than the IS4FIRESv1 values.

1. Introduction

Wild-land fires were recognised among the most-powerful sources of atmospheric tracers, such as CO_2, CO, particulate matter (PM), and precursors for secondary pollutants, several decades ago (Eagan et al., 1974; Crutzen et al., 1979; Seiler and Crutzen, 1980). However, the estimates of fire emissions are arguably known within a factor of a few times, even if large-scale and long-term averages are considered. Estimates of the globally consumed biomass usually range between 5 and 10 Gt annually (Scholes and Andreae, 2000; Chin et al., 2002) with prescribed fires accounting for 3.5–3.9 Gt (Lauk and Erb, 2009). Estimates of released CO_2 also differ within a factor of 2 between different studies, ranging from 1.4 up to 2.8 Mt of carbon per year (Schultz et al., 2008b).

In the most-classic form, the amount of emitted tracer E_i is assumed to be proportional to the area affected by the fires (burnt area) and empirical coefficients characterising the combustion process (Crutzen et al., 1979):

$$E_i = EF_i * BA * BD * CF \quad (1)$$

Here EF is the emission factor for the emitted species i [g/kg dry matter burned], BA is the size of the burned area [km^2], BD is the biomass density [g/kg/km^2], and CF is the combustion completeness factor reflecting combustion efficiency of the fires [dimensionless].

Direct measurements of EFs and combustion efficiency are possible in field and laboratory studies (e.g. Miranda et al., 2005; Campbell et al., 2007; French et al., 2011; Turetsky et al., 2011). The EFs obtained from these experiments are typically used in bottom-up inventories, i.e. extrapolated from the laboratory experiments or field campaign(s) to large-scale applications. Apart from

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extrapolation errors, variables in Eq. (1) also inherit uncertainties: i) the spatial extent and duration of the fires; ii) amount and distribution of available biomass or fuels; iii) fraction of biomass or fuel consumed from the different carbon reservoirs (French et al., 2004).

What seems to be consistent, is that bottom-up burnt-area based approaches tend to underestimate PM emissions but demonstrate better skills for other major tracers (Kaiser et al., 2012a; Sofiev et al., 2009; Van der Werf et al., 2006, 2010). Parallel to burnt-area based algorithms, approaches using active-fire remote-sensing observations have been developed. Historically, the active-fire products started from simple hot-spot counts. Arguably the main problem of the data was the scarcity of the observations. Contrary to burnt-area, the active-fire observations are time-critical: the satellite must register the fire while it burns. The data can be obtained only in cloud-free situation and suffer from infrequent satellite overpasses. For instance, evaluation of ATSR hot-spot product shows correct location of the fires but manifested general under-estimation of their number ((Arino and Plummer, 2001), as reported by Flemming (2005)). Finally, the simple counts were unable to provide information on the fire intensity, which further complicated their quantitative application.

Based on Kaufman et al. (1998a,b) and Ichoku and Kaufman (2005) it is possible to relate the energy of the fire with the rate of biomass consumption and derive a relationship similar to Eq. (1), by relating the physical quantities of the biomass burned (BA*BD*CF) with radiant component of the energy release of the fire. This energy release is the so-called fire radiative power (FRP).

$$E_i = C_{ia} * FRP \qquad (2)$$

Here C_{ia} is the emission coefficient [kg MJ^{-1}].

This approach has been used for several emission inventories (Wooster et al., 2005; Kaiser et al., 2012a; Sofiev et al., 2009; Giglio et al., 2006). Its main challenge is the critical dependence of the estimates on completeness and quality of the fire observations (Schultz et al., 2008). It also requires the algorithm for integrating the observed instant FRP into time-integrated FRE, which is then converted into emission.

The goal of the current paper is to critically review and quantify the uncertainties of the fire PM emission estimations by Integrates System for wild-land Fires (IS4FIRES) v1, which product was used in the second phase of the AQMEII (Air Quality Model Evaluation International Initiative; http://aqmeii.jrc.ec.europa.eu) model intercomparison exercise. The study concerned the summer fire season of 2010 in Eurasia, where severe wildfires occurred due to anomalously high temperatures, in particular over Russia and Portugal.

The next section outlines the methodology of the analysis: models involved and input data. Section 3 quantifies the key contributors to the overall emission uncertainty and presents examples of the new IS4FIRES calibration. The Discussion section analyses the impact of the key uncertainties and presents the outcome of the sensitivity studies.

2. Models and input data

2.1. Remote sensing data

2.1.1. Fire radiative power

The FRP data are obtained from the active-fire observations by Moderate Resolution Imaging Spectro-radiometer (MODIS) instruments on-board Aqua and Terra satellites (http://modis.gsfc.nasa.gov, Justice et al., 2002; Kaufman et al., 1998a,b). This dataset is the only existing collection that covers the whole globe over more than a decade and provides FRP and other characteristics of active fires. We used level-2 data from Collection 5 from both instruments, starting from their first day till November 2012. The raw data – a series of granules, each corresponding to 5 min of the satellite retrievals – are averaged daily to 0.1° spatial resolution. The procedure is described in Sofiev et al. (2009).

FRP products are also available from the Infrared Imager SEVIRI onboard the Meteosat MSG satellite (Kaiser et al., 2009; Roberts and Wooster, 2008). Its pixels are quite large – more than 10×10 km^2 – and often cover many individual fires. Secondly, SEVIRI has limited domain: a circle with radius of about 60°, which covers Africa, Europe except northern Europe, limited areas in Asia and South America. However, high temporal resolution (15 min) makes SEVIRI a valuable source of information about temporal evolution of the fire intensity. Calculations were made using SEVIRI data for three vegetation classes: forest, grass and mixed (Sofiev et al., 2013).

2.1.2. Aerosol optical thickness

The global distribution of the aerosol optical depth (AOD) is provided by the MODIS instruments. We used level-2 data from Collection 5 (before 2009) and 5.1. (Kaufman et al., 2002; Remer et al., 2008). The data were projected to a global $1° \times 1°$ grid: the AOD observations falling into the same grid cell were averaged, for each hour. At least 25 pixels per grid-cell were required to avoid biased AOD values. These two steps ensured the maximum possible co-location of the observations and model results both in space and in time.

2.2. Dispersion model SILAM v.5.3

The model used for calibration and evaluation of IS4FIRES is the System for Integrated modeLling of Atmospheric composition, SILAM (Sofiev et al., 2008). The physical-chemical modules of SILAM cover gas-phase inorganic and organic chemistry, formation of secondary inorganic aerosols, and transformation and removal of size-resolved primary particles of various types (Kouznetsov and Sofiev, 2012; Sofiev, 2000; Sofiev et al., 2006). The system also includes a meteorological pre-processor for evaluation of basic features of the boundary layer and the free troposphere using meteorological fields provided by numerical models (Sofiev et al., 2010). To facilitate the comparison with remote-sensing instruments, AOD at 550 nm was computed for all aerosol components with specific size-spectrum. The optical properties are calculated on the basis of the microphysical data: size distribution and spectral refractive index (Prank, 2008). The fire-induced aerosols were split to two bins – $PM_{2.5}$ for particles from 0.01 μm to 2.5 μm in diameter and $PM_{2.5-10}$ for 2.5 μm–10 μm – assuming homogeneous distribution inside each bin. Other species had their own sectional representation. The extinction coefficients are calculated for the given wave length (550 nm for MODIS AOD) via integrating over the size ranges of the corresponding bins. For the current study, SILAM simulations included anthropogenic (Granier et al., 2011), fire-induced (described in Section 2.3), wind-blown dust and sea salt (Sofiev et al., 2011) emissions. The results shown in this study are based on global runs for time period between 2003 and 2012 with a horizontal resolution of 1*1° and the vertical profile represented by 9 uneven layers reaching up to the tropopause, with the lowest layer being 25 m thick. The model was driven by ERA-Interim meteorological data (Dee et al., 2011). All simulations had the output averaged over 1 h.

2.3. Wild-land fires emissions: IS4FIRES

IS4FIRES is based on the active-fire observation products of MODIS. It compiles the fire emission bottom-up from individual-